ON THE OPERATION OF GEIGER COUNTERS WITH REVERSED POTENTIAL DISTRIBUTION

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ABSTRACT. An account of the studies on the operation of Geiger counters with reversed potential distribution and the effect of heating the axial wire is given. Using a typical set of self-quenching, non-selfquenching and low voltage counters, variations of the parameters like 'pulse-size', 'plateau', 'dead-time' and 'rise-time' associated with counters under different modes of operation are presented. The discharge mechanism of self-quenching counters operated with potentials reversed is discussed in some detail. It is suggested that a radial spread of discharge takes place in the reversed operation of the counter instead of a lengthwise spread associated with normal counters.

INTRODUCTION

In a normal Geiger counter operation, it is customary to maintain the axial wire at a positive potential, as suggested in the original paper of Geiger and Müller (1928). However, Cowie (1935) first attempted to operate a Geiger counter with potentials reversed. Further, Korff (1958) indicated that in some cases of low voltage Geiger counters the behaviour with reversed potentials was just as well as of the counters with normal potential distribution and even better. In this paper it is attempted to give a connected account of the studies on the behaviour of such Geiger counters with reversed potential distribution, that formed a part of the preliminary course of investigations in exploring the possibilities of using a Geiger counter for the detection of thermionic emission at low temperatures with the conventional arrangement of having an axially heated filament as the cathode.

EXPERIMENTAL STUDY OF THE OPERATION OF TYPICAL COUNTERS WITH REVERSED POTENTIALS

(A) *Self-quenching counter* (*with reversed potentials*).

The counter consisted of a pyrex glass tube envelope, whose inner surface was coated with aquadag to form the outer cylinder, having the dimensions 10 cm. by 2·5 cm. The axial tungsten wire had a diameter 0·1 mm. The filling gas was 1 cm. of petroleum ether plus 9 cm. of argon. With the customary negative potential on the outer cylinder, the counter worked perfectly well, having a good plateau with about 99% efficiency for the detection of electrons produced within its working volume.

The situation changed completely with the application of the positive potential on the outer cylinder, in an attempt to operate the counter with reversed potentials. Using a C.R.O. for scanning the pulses, it was soon evident that the counter only operated with extreme characteristics, viz., either it did not count at all or broke down into discharges. The plateau, if any was extremely narrow. Keeping the counter slightly below the discharge potential, no cosmic-ray background could be detected, nor any influence of an external radioactive source. However, by careful adjustment of the counter voltage and the proximity of a source, it could be arranged that the counter responded to a small extent to an external source. But the pulses persisted even after the removal of the source. A plausible explanation of the above findings is the following :

The cosmic or radioactive radiations produce primary ion pairs within the volume of the counter. The electrons are collected by the positive cylinder in the low field region, without producing any Townsend avalanche. If they happen to produce any secondary electrons by the bombardment of the cylinder, these electrons are also collected, without contributing to the continuation of the discharge. The positive ions, consist predominantly of argon ions. The actual number of argon ions N_A is given by

$$\frac{N_A}{N_v} = \frac{P_A\sigma_A}{P_v\sigma_v} \quad .. \quad (1)$$

where N_v is the number of vapour ions, P is the pressure and σ the ionization cross-section of the argon or the vapour as indicated by the subscript. Most of the positive ions, therefore, will be of the vehicular gas, simply because there is so much more of that present. These ions on their way towards the negative axial wire will make collisions with the neutral molecules of the vapour. Since, in general, the ionization potential of the vehicular gas is greater than that of the vapour, conditions are favourable for electron transfer to take place. Thus the reaction :

$$A^{+}+M \rightarrow M^{+}+A+E \quad .. \quad (2)$$

takes place, where A is the Argon atom, M the organic molecule, these symbols with the superscript (+) the corresponding ions and E is energy. The difference in energy, must of course be dissipated, but this can occur as radiation of a photon or as kinetic energy of the two entities involved in the collission. Further, since the free paths between collisions are of the order 10^{-3} to 10^{-4} cm., the ion will make some thousands of collisions on its way to the axial wire, of which collisions this number multiplied by the partial pressure of the vapour will be with vapour molecules. This is a sufficiently large number to ensure that charge transfer will in all probability take place. The result of this process is that all the ions arriving near the axial wire are of the vapour, and not of vehiclar gas. It is a general property of complex molecules that because of the crossing over of the potential energy curves, the energy excess in the molecule upon neutralization does not manifest itself as radiation but gives rise to radiationless transitions, the energy being expended in breaking molecular bonds. Thus in the absence of supply of new electrons to initiate a Townsend avalanche in the vicinity of the wire, there is no pulse to be recorded. It is assumed here that the heavy vapour ion, on account of its low mobility is incapable of producing ionization by collision while approaching the wire.

However, if a primary ionization event takes place in the immediate vicinity of the wire, the outgoing electron will produce Townsend avalanche. The avalanche-produced electrons will move outward towards the positive outer cylinder, while the positive ions, consisting mostly of Argon ions will form a stationary cloud quenching the discharge.

The period of extinction lasts until the positive ion space charge, consisting mostly of A^+ ions, reaches the wire and the last positive ions re-initiate the discharge. This repetitive process behaves like a regular discharge phenomenon, resembling the one occurring at the high voltage end of the plateau of a normal Geiger counter. If the voltage is sufficiently high, the discharge shows a periodicity analogous to Trichel's (1938) periodic corona. Figure 1 shows a photographic oscillogram illustrating the periodicity. If, however, the voltage is lowered to a value when the pulses just appear, one identifies the 'dead-time' phenomenon for a Geiger counter with reversed potentials, as shown in the oscilloscopic pattern in figure 2. For comparison, a photograph of the 'dead-time' oscillogram of the normal Geiger counter is shown in figure 3. It may be noted that there is no gradual growth of pulse size in the case of a reversed potential Geiger counter, which means that the 'dead time' and 'recovery time' are identical.

On account of negligible back-ground of a 'reversed potential' self-quenched Geiger counter, it was considered worthwhile to attempt a new 'low-level' counting technique by coating the axial wire with a small amount of radioactive material. Unfortunately, the idea did not work because of the erratic nature of the secondary electron production by positive ion-bombardment of the wire. Due to the narrowness of the plateau, the pulses easily stepped into the discharge region. In a similar manner, thermionic electrons produced by heating the axial wire also broke into spurious discharge pulses.

DISCHARGE CHARACTERISTICS

Perhaps the most characteristic feature of the normal Geiger type of discharge is found in the complete spreading of discharge along the whole active length of the wire. Meek (1940) suggested that the mechanism of spread is probably akin to the streamer mechanism of spark breakdown. The photons produced in the initial avalanche produce nearby ionization in the counter gas, which is amplified by the radial field and which eventually spreads the discharge to both ends of the counter. Alder *et al* (1947) worked out the theory of the above discharge propagation mechanism and their work was later improved upon by Wilkinson (1948). Several authors have investigated the extent to which the spread of the discharge along the wire can be controlled. For example, Stever (1941, 1942), Wilkening and Kanne (1942), Curran and Rao (1947), Nawijn (1948), Liebson (1947) and Craggs and Jaffe (1947) have investigated various aspects of the subject. Stever appears to have been the first to show that a glass bead mounted on the wire of a fast self-quenched counter may, if the dimensions are suitable, prevent the spread. It shows that the active region of the discharge is localized near the wire. Photoemission from the cathode must be negligible if the localization is to be great. By controlling the variables, i.e., by a reduction in pressure, Stever found it possible to produce discharge spread past the bead. The localizing devices used by Stever and others usually give no appre-, ciable reduction in discharge spread with non-selfquenching counters.

Following Stever's technique a counter was constructed with a small glass bead fixed near the middle of the axial wire. The counter was filled with a mixture of argon and petroleum ether at a pressure of 5 cm. of Hg. During the normal counting, the pulses revealed two different sizes, the bigger pulse being about double the size of the smaller one. Obviously the former were due to fast electrons passing through both segments of the counter and were fewer in number. By passing suitable current through the wire, it was also possible to attenuate the density of the gas in its neighbourhood to such an extent as to enable the discharge spread past the bead and equalize the pulses. When, however, the counter was operated with reversed potentials, all the pulses were of the same size, even without heating the wire. It was therefore evident that the paths along which the discharge spread were different in the two cases. This diagnosis is not very conclusive because the pulses also became equal when the counter with normal potentials was operated in the discharge region i.e., beyond the range of its plateau. It is likely that cathode emission by unabsorbed photons from the avalanches near the wire is responsible for the discharge spread.

Similar experiments were also made with divided cathode tubes. Stever (1941, 1942) and Ramsey (1942) suggested some applications of divided counters containing self-quenching gases, with complete localization of the discharge to the cylinder in which it is initiated. Accordingly two cylinders of aquadag were painted within the same glass envelope, being separated from each other by a gap of 4 cm. The same axial wire passed through the two cylinders, one having twice the length of the other. The combined double counter was filled with a mixture of argon and petroleum ether at a pressure of 5 cm. of Hg. Applying positive potential on the wire, when the pulses were taken from the cathode cylinders consecutively, it was noted that the pulse-size was proportional to the length of the cathode. This disparity in pulse-size remained even when the counter was operated in the discharge region also. However, when negative potential was applied to the axial wire and pulses taken from the outer cylinder as in the previous experiment, it was noted that the pulse-size in the two cases were equal.

The above result indicates that while in the case of a normal counter with positive potential on the wire, the discharge spreads along the length of the counter resulting in a pulse proportional to the length, it spreads radially in the case of a counter operated with negative potential on the wire. This conclusion finds ample support in the cloud chamber pictures of electron avalanches taken by Campion (1954) and Raether (1937) respectively. Figure 4 shows a reproduction of Campion's photograph illustrating the spread of the discharge along the length of the axial anode wire of a Geiger counter enclosed within a cloud chamber, the chamber being triggered by a cosmic ray electron passing through the a ·tive volume of the counter. Figure 5 on the other hand, shows Raether's cloud track picture of a single electron avalanche between two parallel plates with the cathode at the bottom.

Incidentally, it was observed that the pulse-size of a normal self-quenched Geiger counter was invariably smaller than that obtained when it was operated with reversed potentials. This difference in size was much more prominent in the case of a non self-quenching counter. It may be noted in this connection that the positive ions do not produce ionization by collision in the case of a normal Geiger counter, while in the case of a reversed Geiger counter, they do so probably. This factor may be one of the causes for the disparity of pulse-size in the two directions. However, this point needs further investigation. Additional data, regarding the variation of 'pulse-size', 'plateau', 'dead time' and 'rise-time', associated with Geiger counters under different modes of operation, are collectively presented in tables 1 and 2.

(B) *Non Self-quenching counter (With reversed potentials)* :

It consisted of a pyrex glass tube envelope of diameter 2·5 cm., whose inner surface was coated with aquadag to form the outer cylindrical electrode of 10 cm. length. The axial tungsten wire had a diameter of 0·1 mm. The counter was filled with commercial Argon at a pressure of 10 cm. of Hg. With normal potential distribution, the counter worked reasonably well as a slow counter, having an external quenching resistor of 10^{10} ohms,

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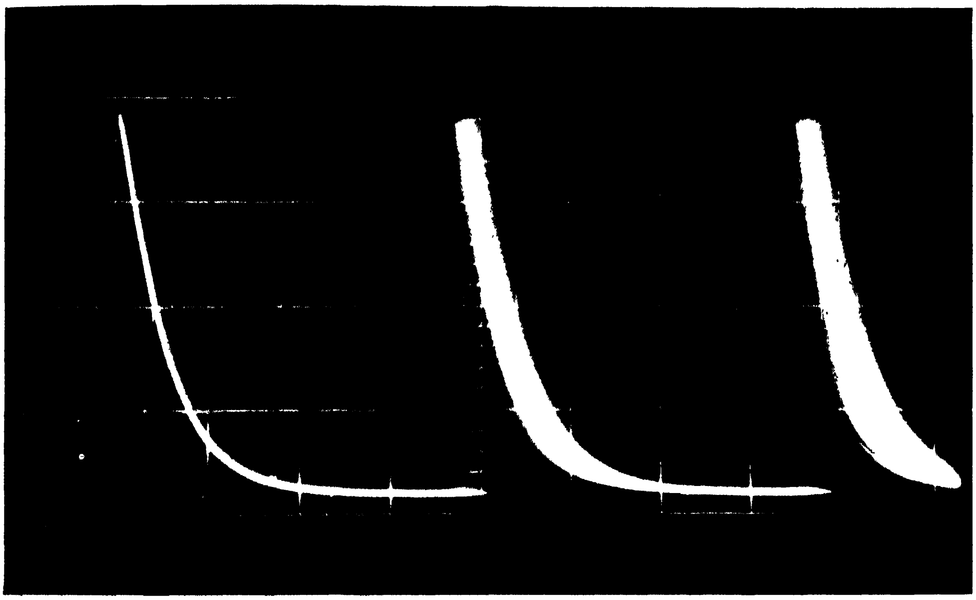

Figure 1. Periodic Corona pulses analogous to Trichel pulses

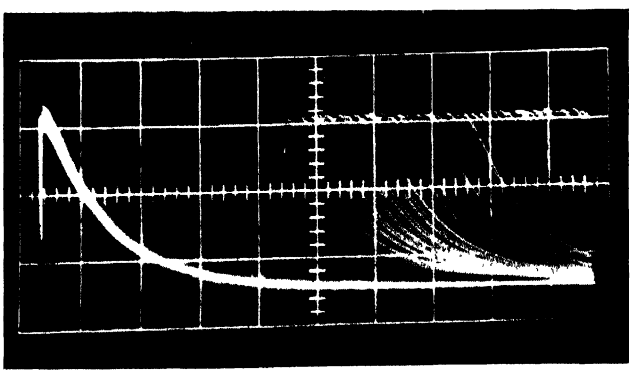

Figure 2. 'Dead-time' in a Geiger counter operated with reversed potentials.

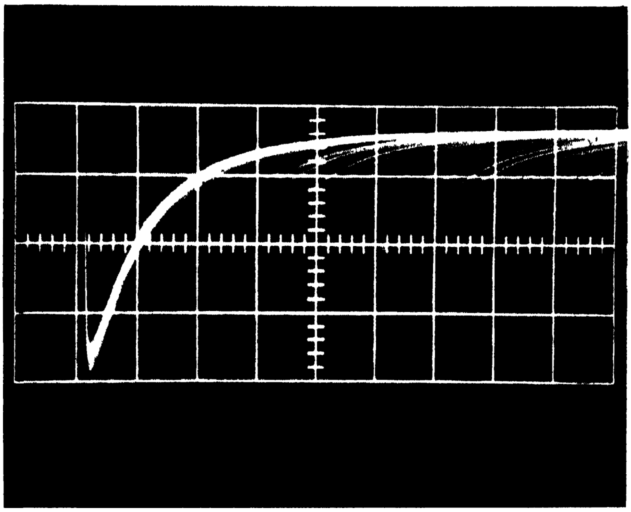

Figure 3. 'Dead-time' in a normally operted Geiger counter.

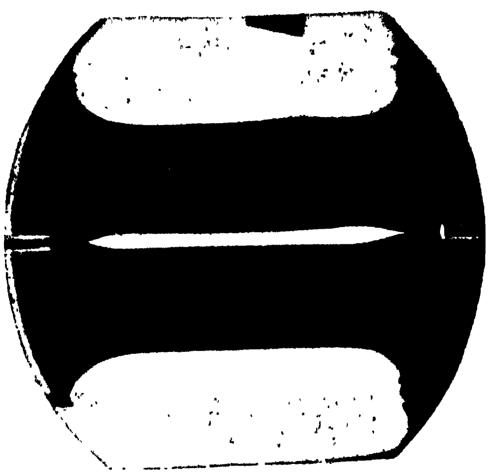

Figure 4. Campion's photograph illustrating the spread of discharge along the length of the axial anode wire of Geiger counter.

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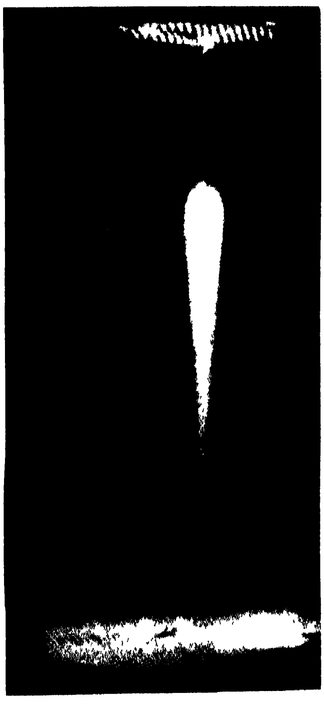


F ire 5. Raether's cloud track picture of a single electron avalcnhe between two parallel plates with the cathode at the bottom.

Table 1
Normal mode of operation

Type of the counter	Pulse size		Plateau		Dead time		Rise time		Remarks
	with over-voltage	with heating of axial wire	without heating	with heating of axial wire	with over-voltage	with heating of axial wire	with over-voltage	with heating of axial wire	
Self-quenching counter.	Increases	Increases	$\simeq$200V	Plateau slightly decreases with temperature.	Decreases	Decreases	Decreases	Decreases	Described more fully in an earlier publication of the authors (1964).
Non-self quenching counter.	Increases	Increases	$\simeq$100V	Plateau slightly decreases with temperature.	—	—	—	—	Plateau and 'dead-time' are governed by the quenching register.
Low voltage counter (Ne+0·012%A) filling.	Increases	Diminishes	$\sim$180V	$\sim$180V	—	—	—	—	..
Low voltage Halogen counter (Philips Type 18503).	Increases	Not tried	$\gtrdot$300V with an upward slope.	Not tried	At first increases and then decreases	Not tried	At first decreases and then remains the same.	Not tried	Heating of the central electrode was not attempted for the following reasons : (i) bigger size (ii) Non-availability of both the terminals of the central electrode.

Table 2
Reverse mode of operation

Type of the counter	Pulse size		Plateau		Dead time		Rise time		Remarks
	with over-voltage	with heating of axial wire	without heating	with heating of axial wire	with over-voltage	with heating of axial wire	with over-voltage	with heating of axial wire	
Self-quenching counter	No change	No change	~10V	~6V	Decreases	Decreases	No change	No change	Within the range of the plateau the dead-time decreases but soon it merges into Trichel type oscillations (Fig. 1).
Non-self quenching counter.	Pulses of different sizes with an external source.	Pulses of different sizes due to cosmic radiation. Thermo-electrons produce pulses of the same size.	~60V	~10V	—	—	—	—	Plateau is governed by the quenching resistor and is steeper than that in the normal direction.
Low voltage counter (Ne+0·012%A) filling.	No change	Slight diminution	~130V	~130V	No change	No change	No change	No change	,,
Low voltage Halogen Counter (Philips Type 18503).	Increases	Not tried	$>$200V	Not tried	Decreases	Not tried	Decreases	Not tried	In the self-quenching region (a small voltage region above the starting voltage) the pulses, if any, are all of the same size. Heating the central electrode was not attempted for the following reasons : (i) bigger size. (ii) Non-availability of both the terminals of the central electrode.

When the potential was reversed, the counter operated under a reduced efficiency. The value of tue relative efficiency ϵ of the reversed counter with respect to the normal counter was 0·21, which compares favourably with Cowie's (1935) value of $\epsilon = 0{\cdot}23$ during his second run of the experiment. Cowie interpreted the inefficiency of the reversed counter by supposing the counter action to be produced when a positive ion strikes the wire and liberates from it a secondary electron. Whenever an electron is so liberated a discharge results, but the probability of liberation is low. Penning (1930) and others have investigated the probability of emission of secondary electrons from tungsten by impact of positive ions of several gases. The number of electrons per ion varies from 0·03 to 0·05 for energies of incident ions below 50 volts and increases nearly linearly with energy upto 0·42 for 1000 volt ions. With the variations of the phenomenon attributable to adsorbed gaseous layers, it seems probable that this range of probabilities stands in agreement with the efficiency found in the above counter experiments.

However, when the axial wire was heated by passing a current through it, the counter action merged into continuous discharge. In this case, the thermal electron produced in the high field region, initiated outward moving electron avalanches, which in turn, produced many positive ions. The localised cloud of positive ions extinguishes the discharge, until the positive space charge reaches the wire and one of the last positive ions liberates a secondary electron which re-initiates the discharge. This process is somewhat less effective in the case of a self-quenched counter, because of the charge transfer from the positive ions of the vehicular gas to the vapour molecules, culminating in the dissociation of the latter.

A similar experiment was performed with a counter filled with hydrogen gas at a pressure of 10 cm. of Hg, with almost identical results.

(C) *Low Voltage Counters* : (*with reversed potentials*)

The following two types of low voltage counters were experimented with :

(1) Simpson (1950) type

and (2) Van Duuren (1961) type

The first type was constructed in our laboratory following Simpson's modus operandi. It consisted of a pyrex glass envelope containing a seamless copper tubing of 1 cm. diameter and 10 cm. length, with a thick layer of Cu_2O on its surface. The oxide layer reduced its photo-sensitivity and contributed to its freedom from spurious pulses at large overvoltages. The axial tungsten wire had a diameter of 0·1 mm. The counter was evacuated with the help of a mercury diffusion pump and simultaneously outgassed at 300°C. With liquid nitrogen around the manifold trap, a mixture of 15 cm. of Ne plus 0·012 per cent A was prepared in the counter. All gases were stated to be "spectroscopically pure".

Any Hg. vapour from the diffusion pump or miniature McLeod gauge was trapped in glass limbs immersed in liquid nitrogen. The threshold voltage for normal counting was 165 V and for reverse counting 307 V. It is apparent that at such pressures of the (Ne 15 cm. +0·012% A) gaseous mixture, the breakdown potential is lower for an anode central wire than for a cathode central wire. The theory of anomalous lowering of breakdown potential has been described by Druyvestyn and Penning (1940). The counter worked satisfactorily with an external quenching resistance of 10^8 ohms in the normal direction with a ready response to an external source of radiation. But, when it was operated with reversed potentials, the response became quite feeble, indicating its inefficiency. An interesting feature was however, noted when this particular counter was operated in the normal direction, while the axial wire was being heated. In this case, the pulse size progressively diminished and ultimately vanished. On the other hand the pulse size increased with overvoltage as previously stated. The explanation of the phenomenon may be sought from a glance at the curve shown in figure 6 showing the breakdown voltage between two co-axial cylinders filled with (Ne+0·002% A)

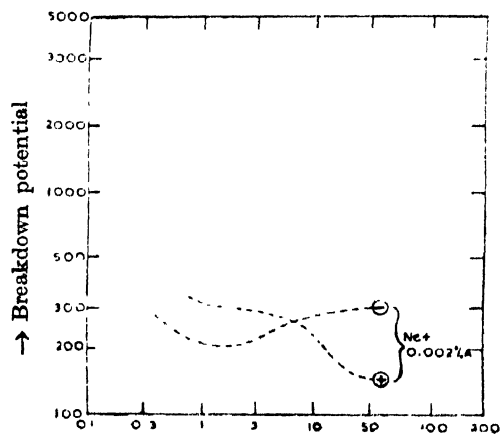


Figure 6. Breakdown voltage versus pressure.

as a function of pressure. It may be seen that the two curves for axial wire anode and cathode respectively intersect at a point and then the former goes downward at higher pressure. Thus, if the pressure is reduced, the breakdown potential may go up. This is equally true for the threshold potential which happens to be situated at the opposite and of the plateau. When the axial wire is heated, the density of the gas mixture in the vicinity of the wire diminishes which is equivalent to the lowering of the gas pressure in the Townsend avalanche region. Consequently the threshold potential rises, culminating in the reduction of the pulse size. This reduction in pulse-size is almost negligible when the central wire is heated as a cathode. Furthermore, the response of the reversed Simpson counter was again very poor to liberated thermo-electrons, although the disturbing effect of the positive ions had been minimised on account of the lower field gradient near the wire. It is probable that the inefficiency of the low voltage counter to thermal electrons liberated along its axis is due to the same cause as in the case of reversed proportional counter, viz., the large straggling of mean free path of thermal electrons in a restricted high field region. The second type of low voltage counter comprises the type described by Van Duuren (1961). Since such counters were readily available in the market under Philip's trade name, some of these were tested according to the schedule. Unfortunately, most of these counters had thick axial wires with only one external terminal, which was unadaptable for the experiment on thermionic emission. Nevertheless, the behaviour of such counters with reversed potentials, was worth studying.

Figure 7 shows a prototype of Philips 18503 counter. It consists of a cylindrical outer electrode of iron chromium alloy of length 4 cm. and diameter 1·44 cm.

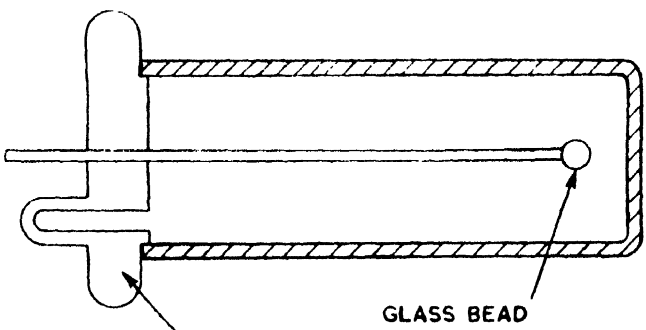
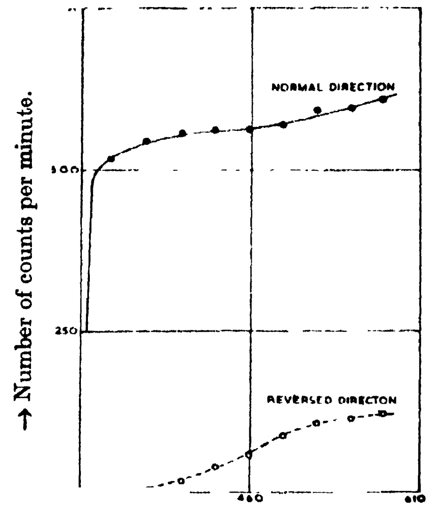


Figure 7. Philips low voltage counter (Type 18503).

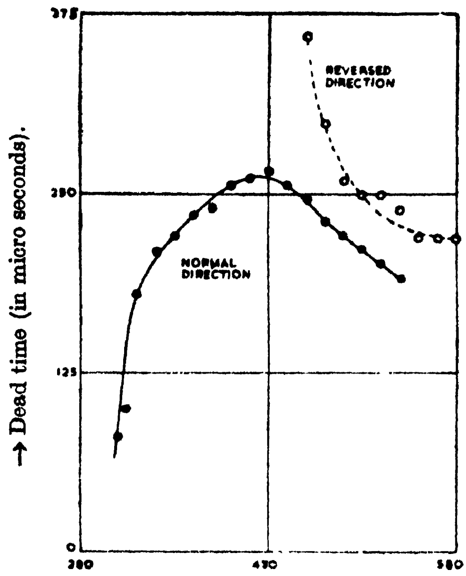
One end of the cylinder is closed by a flat glass disc, coated externally with a black insulating varnish, through the centre of which passes the axial cylindrical electrode of 1 mm. diameter. The other end of the cylinder is closed by a metal cap and the axial cylindrical electrode is terminated with a glass bead very close to this end. The filling gas is a neon-argon halogen mixture of appropriate proportions for a low voltage operation. Figure 8, shows the plateau of the counter in both directions separately. It may be noted that the threshold of the reversed counter is higher than the one for normal operation and the relative efficiency of the reversed counter with respect to the normal counter is 0·076 at an operating potential of 400 V. However, at a higher operating potential 580 V it increases to 0·228. Furthermore, when two counters (Type 18503) almost identical in their normal mode of operation were run in coincidence separated vertically by a distance of 4·3 cm. centre to centre they registered a single coincidence count in a run of 3 hours duration with the potentials reversed while there were 182 coincidence counts in the normal direction, in both cases, the operating potential being kept at 400 V. Hence, the relative efficiency for double coincidences obtained experimentally is $5{\cdot}5 \times 10^{-3}$, which agrees with the theoretically calculated values of



→ Voltage.

Figure 8. Number of counts per minute versus counter voltage.

the efficiency of single counting squared i.e., $(0{\cdot}0765)^2 = 5{\cdot}7 \times 10^{-3}$. A second run at a higher operating potential 580 V registered 9 coincidence counts in the reversed direction and 189 coincidence counts in the normal direction. The relative efficiency obtained experimentally for the double coincidence experiment at the higher voltage comes out to be $9/189 \approx 4{\cdot}7 \times 10^{-3}$ which also agrees



→ Voltage.

Figure 9. Dead-time versus counter voltage.

with the calculated value of $\epsilon^2 = 5{\cdot}1 \times 10^{-3}$. Thus, the relative efficiencies ϵ^2 for the coincidence calculated from the above figures for the single counting in the two cases, compare favourably with the experimental values within the limits of statistical accuracy. Figure 9 shows the dependence of dead time with

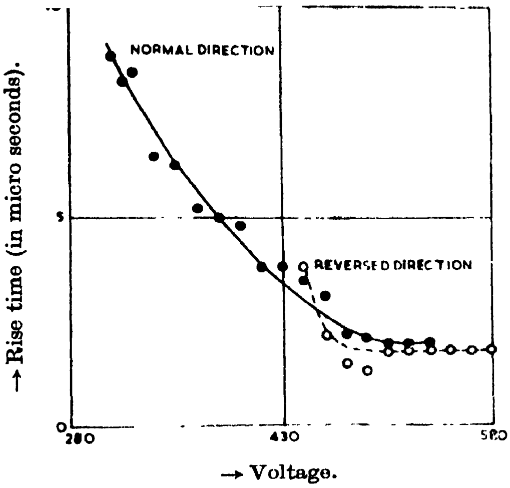


Figure 10. Rise-time versus counter voltage.

counter voltage in either case. The hump on the dead time curve for the central electrode positive has been explained by Van Duuren as being due to the state

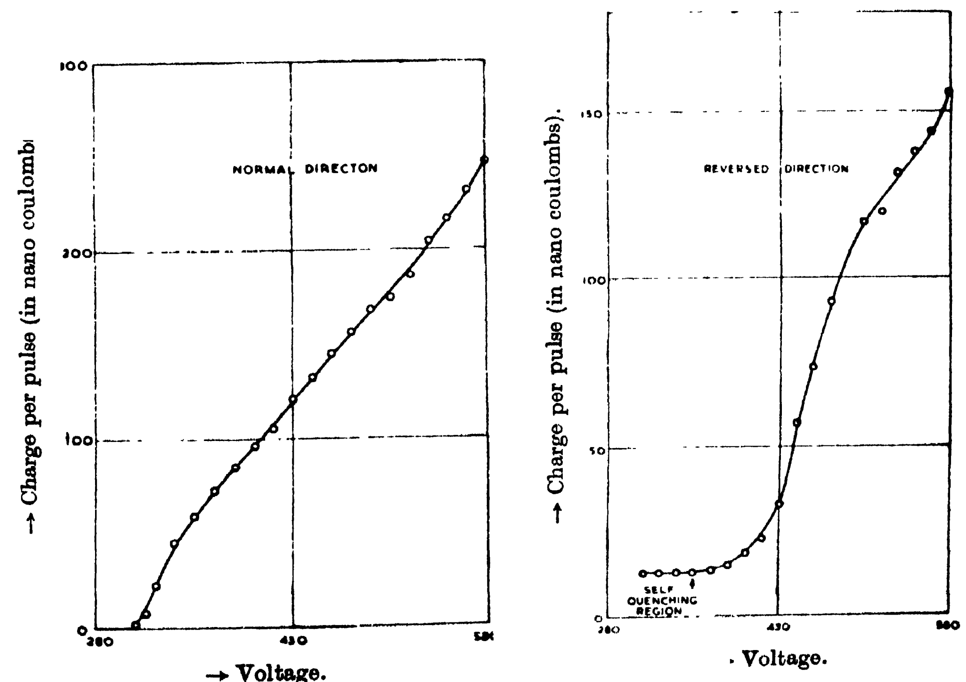


Figure 11. Charge per pulse versus counter voltage.

of transition of the counter from the self-quenching to the non-self quenching type. Figure 10 represents the variation of rise time for this counter in either mode of operation. Figure 11 shows the dependence of pulse size on counter voltage in either case. It may be noted that for the reversed operation the pulse size is independent of counter voltage so long as the counter operates in the self-quenching region.

The collected data of operating parameters for various types of counters are presented in tables 1 and 2.

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